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# Carbon Dioxide Emissions and Environmental Impact of Different Surgical Modalities of Hysterectomies

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## ABSTRACT

**Background and Objectives:** The objectives of this study were to determine carbon dioxide ($CO_2$) emissions generated from nonreusable waste and compare across different types of hysterectomies for benign and malignant indications. Overall greenhouse gas emissions were not examined.

**Methods:** This is a prospective cohort study that identified women undergoing a robotic assisted, laparoscopic, vaginal, or abdominal hysterectomy for any indication. The amount of waste generated was collected for each case, along with patient demographics, and details of the procedure. Weight of waste was converted to kilograms of $CO_2$ emissions using the following formula:

$$\begin{aligned} \textit{Carbon dioxide emissions} = {} & \textit{Waste in pounds} \\ & \times \textit{1 Short ton/2000 pounds} \\ & \times \textit{Emission factor}\,(\mathrm{kg\,CO_2}/\textit{short ton}) \\ & \times \textit{Global warming potential}\,(\textit{GWP}) \end{aligned}$$

We extrapolated the amount of $CO_2$ emissions produced to the number of hysterectomies performed annually in the United States.

**Results:** We found that robotic hysterectomies generated the highest mean $CO_2$ emissions (12.01 kg $CO_2$), while vaginal hysterectomies produced the lowest mean $CO_2$ emissions of 4.48 kg ($p < .0001$).

Our sample size of 100 hysterectomies was equivalent to 1099.4 kg $CO_2$ emissions. When our results were extrapolated, all hysterectomies in the United States produce 5.7 million kg of $CO_2$ emissions. This is equivalent to 234,513 airplane miles, and 95 trips cross-country across the USA from New York, New York to Los Angeles, California.

**Conclusion:** Robotic hysterectomies generated a statistically significant majority of $CO_2$ emissions. Therefore, robotic surgery, as currently practiced, may offer a good initial opportunity for decreasing the carbon footprint of surgery.


**Key Words:** Environmental sustainability, Hysterectomy, Laparoscopy, Minimally invasive gynecologic surgery, Robotic surgery.

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## INTRODUCTION

The healthcare industry is a prominent contributor to greenhouse gas emissions, with the United States (US) health care system contributing about a quarter of all health care emissions worldwide.[1] There are many sources of greenhouse gas emissions to consider, including direct emissions from health care facilities including anesthetic gases as well as indirect emissions such as waste generated from production and elimination of different items, usage of goods and electricity consumed.[1] Previous studies have shown that the operating room generates a significant amount of waste including anesthetics, surgical materials, and energy sources.[2]

Hysterectomies are the second most common type of surgery performed on women in the US, with an estimated 516,793 performed annually.[3] Therefore, we investigated the environmental impact of performing this surgery at a single community-based teaching hospital, level 2 trauma center. Our focus is centered around disposable waste generated during different routes of hysterectomy, as there is very limited information in the literature surrounding this.

The different approaches to hysterectomy include robotic, laparoscopic, abdominal, and vaginal. Each approach requires different types of instrumentation, materials, and surgical draping. The technology behind robotic surgery is expected to rapidly evolve in the next few years. There are many robotic platforms that exist at various stages of development, and it is important to acknowledge that each platform differs in terms of waste produced and greenhouse gases emitted. Our institution solely utilizes the Da Vinci Robotic platform by Intuitive Surgical in Sunnyvale, CA, USA. Generally, robotic hysterectomies performed using this system require robot arm drapes, robotic endoscope camera, fenestrated bipolar forceps, monopolar scissors, ProGrasp forceps and sometimes a Vessel Sealer (all Intuitive Surgical, Sunnyvale, CA, USA). Energy devices that were used for laparoscopic hysterectomies include Thunderbeat (Olympus, Westborough, MA, USA), Harmonic (Ethicon, Raritan, NJ, USA), Ligasure (Covidien, Minneapolis, MN, USA), or monopolar hook. Most of these devices are reusable and were not included in the weight of the waste. Uterine manipulators are often used for both laparoscopic and robotic hysterectomies. Abdominal hysterectomies require large amounts of instrumentation and sutures, and sometimes disposable equipment. Vaginal hysterectomies require sutures and are performed in lithotomy position with use of moderate amount of draping.

The objectives of this study were to determine carbon dioxide ($CO_2$) emissions generated from nonreusable waste and compare across all types of hysterectomies for either benign or malignant indications. We hypothesized that there will be a significant difference of waste generated by type of hysterectomy, which may help guide further targeted interventions to reduce our environmental impact. We recognize that there are many advancements in the field of medicine and surgical approaches. However, it is critical to understand the impact these advancements have on the environment.

## MATERIALS AND METHODS

This institutional review board (IRB)-approved prospective cohort study included women 18 years or older who underwent a robotic assisted, laparoscopic, vaginal, or abdominal hysterectomy for any indication from November 1, 2021 – July 31, 2022. We excluded women who underwent emergent hysterectomies (i.e., postpartum hysterectomy). Prior to study initiation, this study protocol was reviewed and approved as exempt WCG IRB Work Order #1–1489275-1 by our institution's IRB of record. We were granted a waiver of informed consent as well as a full HIPAA waiver to conduct this research. Institutional Scope of Practice protocols as well as the nature of data collection with proper confidentiality measures in place led to the IRB determining the research is exempt from continuing review.

A total of 100 patients were included in our study. Demographics were collected including age, body mass index, race and ethnicity, and medical and surgical comorbidities. Details of the procedure were also collected for each patient including the route and type of hysterectomy, other concurrent procedures that took place at time of hysterectomy, the indication, the surgeon who performed the case, duration of the case, total time spent in the operating room, estimated blood loss (EBL), and number of individuals scrubbed. Data on the waste generated included number of trash bags, number of recycling bags, total weight of trash bags, and if reusable instruments were used such as energy devices during robotics procedures. Waste generated during a surgical case generally includes laparoscopic nonreusable instruments, surgical and robotic arm drapes, patient positioning kit including the "Pink Pad" (Xodus Medical, New Kensington, PA, USA), surgical gowns and gloves, plastic covers for instruments, and sponges from surgical tray. We weighed the nonreusable waste using "Etekcity Digital Portable Handheld Scale" (Vesync Co., Anaheim, CA, USA), after the device was approved by our institution.

The amount of waste generated for each surgical case was converted to kilograms of $CO_2$ emissions using the following formula.

$$CO_2\,emissions = Waste\ in\ pounds\ (lbs) \times 1\ Short\ ton / 2000\ lbs \times Emission\ factor \times Global\ warming\ potential\ (GWP)$$

Emission factor (kg $CO_2$/short ton) is obtained from the Environmental Protection Agency's "Emission Factors for Greenhouse Gas Inventories".[4] Global warming potential for $CO_2$ is equivalent to a factor of one. The weighted sum of $CO_2$ emissions generated by the 100 hysterectomies was extrapolated to estimate the amount of $CO_2$ emissions produced by the 516,793 hysterectomies that are performed annually in the US. We converted $CO_2$ emissions to air miles travelled for some perspective on its environmental impact. On average, a plane produces 53.3 pounds of $CO_2$ per mile.[5]

### Statistical Analysis

Deidentified data was collected into a database and analyzed using SAS version 9.4. For discrete variables, count and percentages include results for the univariate $\chi^2$ tests of association. Fisher's exact tests were used when expected frequencies within cells were less than five patients. For continuous variables like weight of trash bags (lbs), $CO_2$ emissions (kg) and estimated blood loss (mL), group analysis of variance (ANOVA) was used to compare the cohorts by route of hysterectomy and reported with means and standard deviations and 95% confidence interval (**Table 1**). Two-way ANOVA test was performed to assess the association between the surgeon who performed the case and the amount of waste generated. Posthoc stratification would be performed for significant results of ANOVA test (**Table 2**). To examine the association between the duration of case and the amount of waste, Pearson correlation was performed, correlation ranging from –1 to 1. A $P$-value of 0.05 ($P < 0.05$) defined reaching statistical significance for each analysis and likelihood of type I error would be considered. Due to the exploratory nature of this analysis, there were no corrections applied for multiple comparisons.

Total amount of $CO_2$ emission in all hysterectomies was obtained using the formula from the Environmental Protection Agency and was extrapolated with 2010 national data on annual hysterectomies performed.[4]

$$CO_2\,emissions = Waste\ in\ pounds\,(lbs) \times 1\ Short\ ton/2000\,lbs \times Emission\,factor \times Global\ warming\ potential\,(GWP)$$

**Table 1.**
Mean $CO_2$ Emission (kg) by All Hysterectomies

| Route of Hysterectomy | $CO_2$ Emission (kg) Mean (Standard Deviation) | 95% Confidence Interval | $P$-value |
|---|---|---|---|
| Abdominal | 7.08 (1.6) | 5.6–8.6 | <.0001 |
| Laparoscopic | 10.7 (1.7) | 10.1–11.3 | |
| Robotic | 12.01 (1.3) | 11.6–12.4 | |
| Vaginal | 4.5 (0.8) | 2.5–6.5 | |

**Table 2.**
Post-hoc Stratification

| Route of Hysterectomy Comparison | Mean Difference $CO_2$ Emission (kg) | 95% Confidence Interval |
|---|---|---|
| Robotic vs. Laparoscopic | 1.3 | 0.5–2.1 |
| Robotic vs. Abdominal | 4.9 | 3.3–6.5 |
| Robotic vs. Vaginal | 7.5 | 5.2–9.8 |
| Laparoscopic vs. Abdominal | 3.6 | 2.0–5.2 |
| Abdominal vs. Vaginal | 2.6 | −0.04–5.2* |
| Laparoscopic vs. Vaginal | 6.2 | 3.9 – 8.5 |

*Not significant.

- Emission factor (kg $CO_2$/short ton) obtained from the Environmental Protection Agency's "Emission Factors for Greenhouse Gas Inventories."[4]
- GWP for $CO_2$ is Equivalent to a Factor of One

The amount of $CO_2$ emission produced was compared with equivalent airplane miles (1 air mile = 53.3 pounds of $CO_2$).

## RESULTS

A total of 100 patients who met inclusion criteria underwent a hysterectomy performed by nine different surgeons. Between November 1, 2021 – July 31, 2022, we performed seven abdominal hysterectomies, 34 laparoscopic hysterectomies, 56 robotic hysterectomies, and three vaginal hysterectomies.

Indications for hysterectomy among our cohort included fibroid uterus (36%), abnormal uterine bleeding/postmenopausal bleeding (25%), endometriosis/adenomyosis (4%), persistent cervical dysplasia (4%), endometrial hyperplasia (2%), adnexal mass (7%), pelvic pain (1%), pelvic organ prolapse (2%), and gynecologic malignancy (19%).

Demographics were analyzed and there was no statistically significant difference by race and ethnicity among the different routes of hysterectomy. There was also no statistically significant difference between mean body mass index among those who underwent abdominal (26.7), laparoscopic (29.2), robotic (26.7) and vaginal (30.0) hysterectomies. However, there was a statistically significant difference between mean age among those who underwent abdominal (48.6 years), laparoscopic (57.9 years), robotic (53.5 years) and vaginal (68.3 years)

**Table 3.**
Clinical Variables by Route of Hysterectomy

| | Route of Hysterectomy (n = 100) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Abdominal | | Laparoscopic | | Robotic | | Vaginal | | |
| Variable | Mean | SD | Mean | SD | Mean | SD | Mean | SD | *P*-value |
| Duration of case (min) | 154.3 | 78.4 | 112.2 | 43.9 | 112.6 | 47.8 | 70.3 | 5.5 | 07 |
| Estimated blood loss (mL) | 461.4 | 334.3 | 79.4 | 118.7 | 57.9 | 63.8 | 83.3 | 28.9 | <.0001 |
| Number of surgical gowns used | 6.1 | 2.3 | 5.6 | 1.4 | 7.1 | 1.5 | 4.0 | 0 | <.0001 |
| Number of trash bags | 1.3 | 0.4 | 1.5 | 0.5 | 1.9 | 0.5 | 1.0 | 0 | .0004 |

SD, Standard deviation.

hysterectomies ($P = 0.04$). The youngest aged patient in the vaginal hysterectomy group was 68 years old, and the youngest in the abdominal hysterectomy group was 48 years old. Patients who underwent vaginal hysterectomies had concurrent pelvic organ prolapse procedures, which generally occurs in an older population. This may explain the age difference between hysterectomy groups.

EBL, number of surgical gowns used, and number of trash bags used were statistically significantly different between all routes of hysterectomy (**Table 3**). EBL ranged from 57.9 mL (robotic) to 461.4 mL (abdominal) ($P < 0.0001$). The number of surgical gowns used ranged from 4.0 (vaginal) to 7.1 (robotic) ($P < 0.0001$). The number of trash bags used were statistically different by type of hysterectomy ($P = 0.0004$). There was no significant difference in duration of case between types of hysterectomies. There was a statistically significant difference in waste generated by surgeon performing robotic hysterectomy ($P = 0.02$) (**Table 4**).

There was a significant linear correlation between duration of surgical case and weight of nonreusable waste (**Figure 1**). The longest duration of surgical case and highest $CO_2$ emissions were generated during cases indicated for endometrial hyperplasia and pelvic pain (**Table 5** and **6**). However, there is no strong correlation between duration of surgery and $CO_2$ emissions generated (correlation coefficient = 0.21, $P = 0.03$).

The average waste generated by each type of hysterectomy ranges from lowest (vaginal, 9.9 lbs) to highest (robotic, 26.6 lbs) ($P < 0.0001$) (**Figure 2**). After the conversion was performed, a significant difference was found between mean $CO_2$ emissions by route of hysterectomy was noted ($P < 0.0001$).

In order to quantify the environmental impact of gynecologic surgery, we used the Blue Sky Model to determine that an airplane produces approximately 53 pounds of $CO_2$ per air mile.[5] We then extrapolated our weighted total of $CO_2$ emissions produced by 100 hysterectomies (**Table 7**) to the 516,793 hysterectomies performed annually in the US to be 5.7 million kg of $CO_2$ emissions. This was then converted to airplane miles and is equivalent to 95 cross-country trips across the USA from New York, New York to Los Angeles, California.

## DISCUSSION

### Principal Findings

We found that robotic hysterectomies generated the most $CO_2$ emissions (12.0 kg $CO_2$ per hysterectomy) in comparison to all other types of hysterectomies, including laparoscopic, abdominal, and vaginal. Vaginal

**Table 4.**
Mean Waste Generated by Individual Surgeon

| Surgeon | Robotic Surgeries (N) | Mean Waste in Pounds (Standard Deviation) | *P*-value |
|---|---|---|---|
| 1 | 2 | 29.86 (4.12) | 0.02 |
| 2 | 12 | 26.62 (2.08) | |
| 3 | 30 | 25.67 (2.98) | |
| 4 | 10 | 28.85 (2.26) | |
| 5 | 1 | 29.15 | |
| 6 | 1 | 24.42 | |

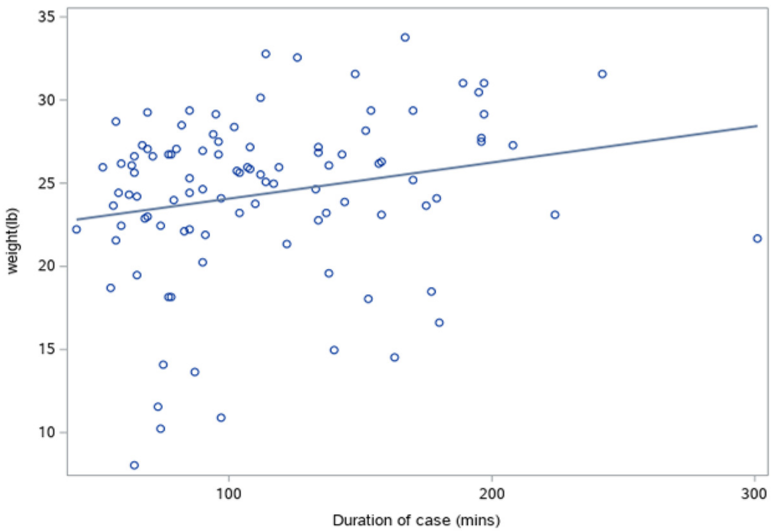


**Figure 1.** Linear correlation between duration of case (minutes) and weight of nonreusable waste (pounds).

hysterectomies produced the lowest mean $CO_2$ emissions of 4.5 kg per hysterectomy ($p < 0.0001$). Our entire sample size of 100 hysterectomies is equivalent to a total of 1099.4 kg $CO_2$ emissions. There was a positive correlation between duration of surgery and waste generated (**Figure 1**).

## Results in the Context of What is Known

There are a limited number of studies that have investigated the topic of environmental impact and sustainability of gynecologic surgeries. One prior study, Woods et al. published in 2015, looked at the waste production and energy consumption of 150 staging procedures performed for endometrial cancer either robotically assisted laparoscopy, conventional laparoscopy, or laparotomy.[6] The carbon footprint of these cases was compared, and they similarly found that robotic-assisted cases have the largest amount of $CO_2$ emissions in the context of endometrial cancer staging, followed by laparoscopy, and then laparotomy. Our findings corroborate theirs for both benign and malignant indications.

Another study by Thiel et al. 2015 utilized the Life Cycle Assessment tool that analyzes a product's environmental impact through all stages of its processing, from production to disposal.[7] This study included patients who undergoing any form of hysterectomy (vaginal, abdominal, laparoscopic, or robotic) for benign indications. The authors identified a significant impact of anesthetic gases, production of certain disposable products on the environment. They additionally found that robotic hysterectomies produced 30% more waste in comparison to the average of all other approaches, similarly, reported in the present study.

## Clinical Implications

The results of our study have several important clinical implications at the national level. An estimated 516,793 hysterectomies are performed annually in the US.[3] If we extrapolate from our results, 516,793 hysterectomies annually will produce 5.7 million kg of $CO_2$ emissions.[3,5] This is equivalent to 234,513 airplane miles, which for

**Table 5.**
Length of Surgery (Mins) by Indication of Procedure

| Indication of Surgery | N | Mean (Standard Deviation) | *P*-value |
|---|---|---|---|
| Fibroids | 36 | 111.3 (47.85) | 0.04 |
| Abnormal uterine bleeding/postmenopausal bleeding | 25 | 107.72 (48.13) | |
| Endometriosis/adenomyosis | 4 | 99.00 (34.26) | |
| Cervical dysplasia | 4 | 95.75 (31.02) | |
| Endometrial hyperplasia | 2 | 160.50 (9.19) | |
| Gynecologic malignancy | 19 | 139.57 (52.82) | |
| Adnexal mass | 7 | 87.57 (46.05) | |
| Pelvic pain | 1 | 208.00 | |
| Pelvic organ prolapse | 2 | 69.00 (7.07) | |

**Table 6.**
$CO_2$ Emissions (kg) by Indication of Surgery

| Indication of Surgery | N | Mean (SD) | *P*-value |
|---|---|---|---|
| Fibroids | 36 | 11.32 (2.19) | 0.0001 |
| Abnormal uterine bleeding/postmenopausal bleeding | 25 | 11.12 (2.06) | |
| Endometriosis/adenomyosis | 4 | 12.61 (1.64) | |
| Cervical dysplasia | 4 | 10.76 (1.80) | |
| Endometrial hyperplasia | 2 | 14.24 (1.40) | |
| Gynecologic malignancy | 19 | 10.32 (1.89) | |
| Adnexal mass | 7 | 10.73 (0.91) | |
| Pelvic pain | 1 | 12.30 | |
| Pelvic organ prolapse | 2 | 4.12 (0.70) | |

**Table 7.**
Total Amount of $CO_2$ Emissions by All Hysterectomies

| Route of Hysterectomy | Sum of $CO_2$ Emission (kg) | Percentage (%) |
|---|---|---|
| Abdominal | 49.6 | 7 |
| Laparoscopic | 363.8 | 34 |
| Robotic | 672.6 | 56 |
| Vaginal | 13.4 | 3 |
| Total | 1099.4 | 100 |

some perspective, is equivalent to 95 cross-country trips from New York, NY to Los Angeles, CA.

Identifying and understanding the environmental impact of our surgical interventions is vital when determining how to make the operating room sustainable. Ultimately, this will help guide us to create reduction strategies, such as promoting the recycling of materials and primarily using reusable materials.

## Research Implications

Like Thiel et al. 2015, future studies may consider to further investigate waste generated by anesthesia, the quantity of $CO_2$ used during insufflation for robotics or laparoscopic procedures, and the transportation needed to and from waste disposal sites and its associated greenhouse gas emissions. Also, future studies may consider accounting for the additional waste generated when an overnight hospital stay is required postoperatively.

## Strengths and Limitations

Strengths of our study include a representative sample of patients at our institution, the study's prospective nature, and detailed analysis of waste generated and $CO_2$ emissions produced by all types of hysterectomies. Our study also calculated the impact on a national level and highlights the importance of sustainability in medicine and health systems. While waste generated is an important component of greenhouse gas emissions, there are other important factors to also consider including $CO_2$ emissions generated to produce different items, anesthetic gases, and time patients spent in the hospital. Therefore, our study is somewhat limited in scope. Other weaknesses include a single institution review, and the unknown generalizability of our findings to other hospital systems and other

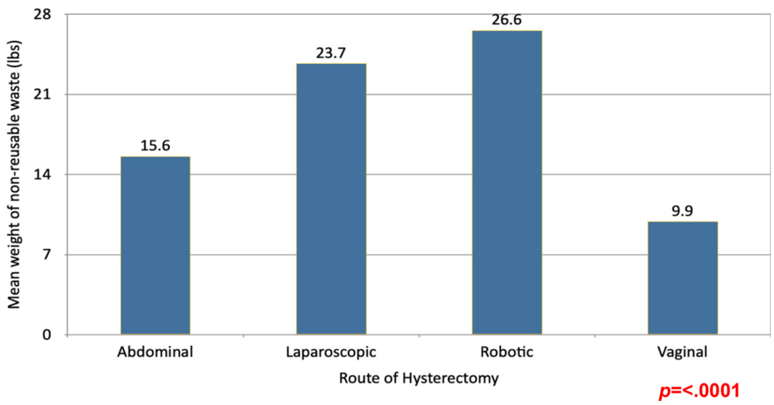


**Figure 2.** Mean weight of nonreusable waste (pounds) by different routes of hysterectomy.

surgical procedures. Additionally, while there were only three vaginal hysterectomies in our study population, we compared the mean of each route of hysterectomy to allow for a fairer comparison.

## CONCLUSIONS

Robotic hysterectomies at our institution have the largest environmental impact when compared to all other types of hysterectomies for both benign and malignant indications. The vaginal approach generated the lowest $CO_2$ emissions. Therefore, robotic surgery, as currently practiced, may offer a good initial opportunity for decreasing the carbon footprint of surgery. These findings are consistent with prior studies that evaluated environmental impact of gynecologic surgeries. For example, Woods et al. found that among endometrial cancer cases, robotic-assisted surgeries produce the largest amount of $CO_2$ emissions.[6] Thiel et al. also found that robotic hysterectomies produce 30% more waste than all other hysterectomies.[7] We hope that our study will help to formulate initiatives to better quantify the environmental impact of gynecologic surgeries. Additional research is needed to investigate waste generated by anesthesia, the quantity of $CO_2$ used during insufflation for robotics or laparoscopic procedures, and the transportation needed to and from waste disposal sites. Next steps could also include conducting a cost analysis to have a better understanding of the relationship between cost and patient outcomes. This would require a detailed analysis of not only cost of the instruments used, but also cost of production and disposal, cost to the insurance companies, and to the patients.

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